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# System for Detection of Small Inclusions in Large Optics

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# System for Detection of Small Inclusions in Large Optics.

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## ABSTRACT

The presence of defects in optical materials can lead to bulk damage or downstream modulation and subsequent surface damage in high fluence laser systems. An inclusion detection system has been developed by the National Ignition Facility Optics Metrology Group. The system detects small inclusions in optical materials with increased sensitivity and speed over previous methods. The system has detected all known inclusions and defects and has detected previously undetected defects smaller than 5 microns.

**Keywords:** Laser damage, inclusions, bulk damage.

## 1. MOTIVATION

Inclusions in the bulk of optical materials have been known to lead to laser damage[1,2]. During testing of optical materials for high fluence laser systems, it was determined that small inclusions were present in the material bulk that escaped previously existing inspection systems. These inclusions left the optical material more susceptible to laser damage. Detection of these defects, potentially smaller than 5 microns, using inspection tools available at the time proved to be time consuming and unreliable. A system was needed to rapidly inspect optical materials to ensure that the material in its blank form was free of inclusions prior to investing resources in the material.

If a defect is found in the bulk of the material prior to finishing the material can be efficiently used. It may be used in an optic where the defect will not cause damage, or the optic finished in a way that the defect is outside the used area of the optic or is ground away during processing. Multiple optics are cut from a boule or casting so there is flexibility to cut around inclusions.

## 2. REQUIREMENTS

### 2.1 Scan Time

The required scan time for each optic blank is less than 8 hours. This timeframe ensures that this inspection step is not the limiting factor in blank production rates.

### 2.2 Sensitivity

The system must reliably detect defects 5 microns in diameter and larger with a goal of detection of 1 micron diameter defects.

### 2.3 Material

The system is required to be capable of inspecting typical optical blanks as received from vendors. The blanks have dimensions of up to 500 mm x 500mm x 80 mm thick and may be wedged. The faces of the blanks are inspection (or commercial) polished and all edges are ground.

In addition to blanks, the system is required to be able to inspect finished optics with curved and wedged surfaces.

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## 2.4 Notes

The inspection system and requirements reflect an intent to detect inclusions and not to perform full charactization. The intent is that this tool detects defects and provides a location; higher precision but slower tools will then inspect the defect and determine its characteristics.

The requirements were largely driven by a small set of sample inclusions. These samples contained inclusions that were difficult or impossible to detect using previously existing large area inspection tools.

The inclusions of interest contain discrete index changes. The system was not intended to detect smooth gradual index inhomogeneities.

# 3. CONCEPT AND CHALLENGES

The inclusions of interest are ~5 microns with an index near the bulk index of a 500 mm x 500 mm x 80 mm blank. In rough numbers, one defect occupies $6 \times 10^{-26}$ of the volume of the blank. The detection scheme must be able to scan the entire volume of the blank with high sensitively, high reliability, and speed. Based on experience and available tools, early investigations and the eventual solution centered on detecting laser light scattered by the inclusions.

## 3.1 Automated Inclusion Mapper (AIM) concept

The Automated Inclusion Mapper (AIM) concept is shown in figure 1. The probe beam passes through the optical material. The plane of the probe beam is imaged onto the CCD camera through the edge of the optical material. Defects on the surfaces and in the bulk scatter light from the probe beam. This scattered light is then imaged onto the CCD. Image processing routines analyze the images to determine if any defects are present in the bulk.

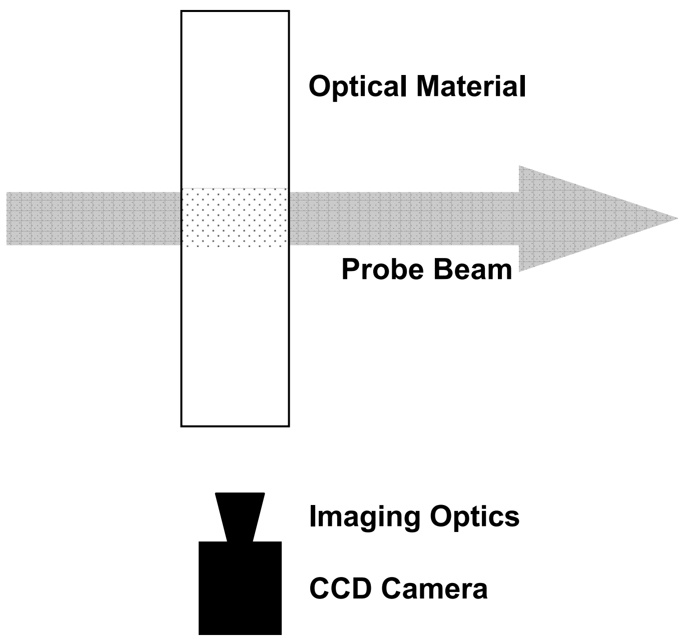


Figure 1: Conceptual diagram of the AIM system. The probe beam passes through the material under test. Defects in the material scatter light. This scattered light is then imaged onto the CCD camera.

## 3.2 Bulk Scatter

The bulk scatter signal can be much larger that the scatter signal from an inclusion. In early testing using a photomultiplier tube to detect changes in scattered signal, the signal from a defect free 50 $mm^3$ volume was 95% of the signal for a 50 $mm^3$ volume containing a 15 micron diameter defect. In this same volume, 5 micron defects were undetectable. Figure 2 is an enhanced image showing a defect in the bulk along with significant bulk scatter.

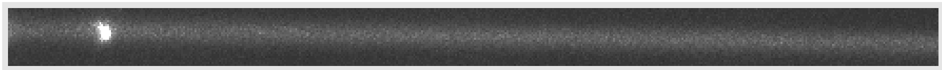

Figure 2: Enhanced image of defect in bulk. Note bright band passing through image, in a non-imaging system this scattered light is the background signal.

To reduce the impact of bulk scatter, an imaging system was developed. In this system, each pixel collects light from a 0.01 $mm^3$ volume. There is no significant bulk scatter signal from the small volume and defects are readily detected.

### 3.3 Surface contributions

As given in the requirements, the system must be capable of testing optics with inspection polished surfaces. These surfaces regularly have defects larger than 100 microns in diameter that scatter a large amount of laser light. Any detection scheme must have high rejection of surface scatter. Figure 3 shows an inclusion map from an early version of the system detecting forward scattered light. This sample had no inclusions, however defects on surface scattered light and were detected as internal defects.

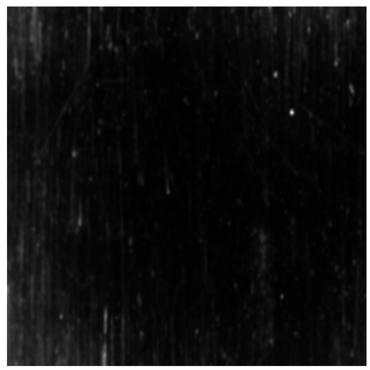

Figure 3: Light areas are "detected" defects. No inclusions were present in this part.

Combining a camera with viewing the bulk from the side enables separation of surface defects from bulk defects. Figure 4 shows a typical image of a defect from the detection camera. Both the internal defect and surface scatter can be clearly seen in this image, illustrating that the surface and bulk defects are separate and easily distinguishable.

Figure 4: Image from CCD camera. Note that edges of optic and defect are clearly separable.

## 4. IMPLEMETATION

A schematic of the inclusion detection system is shown in figures 5 and 6. The optic is raster scanned through the stationary laser beam. A CCD camera captures the scattered light from the laser path through the optic under test. As the optic under test is moving relative to the laser beam, the effective distance between the camera and the laser plane (object plane) is constantly changing as the scattered light is passing through changing thicknesses of glass. To maintain focus and magnification, the camera is on a separate stage moving at 33% of the speed of the optic under test (for optical materials with an index ~1.5).

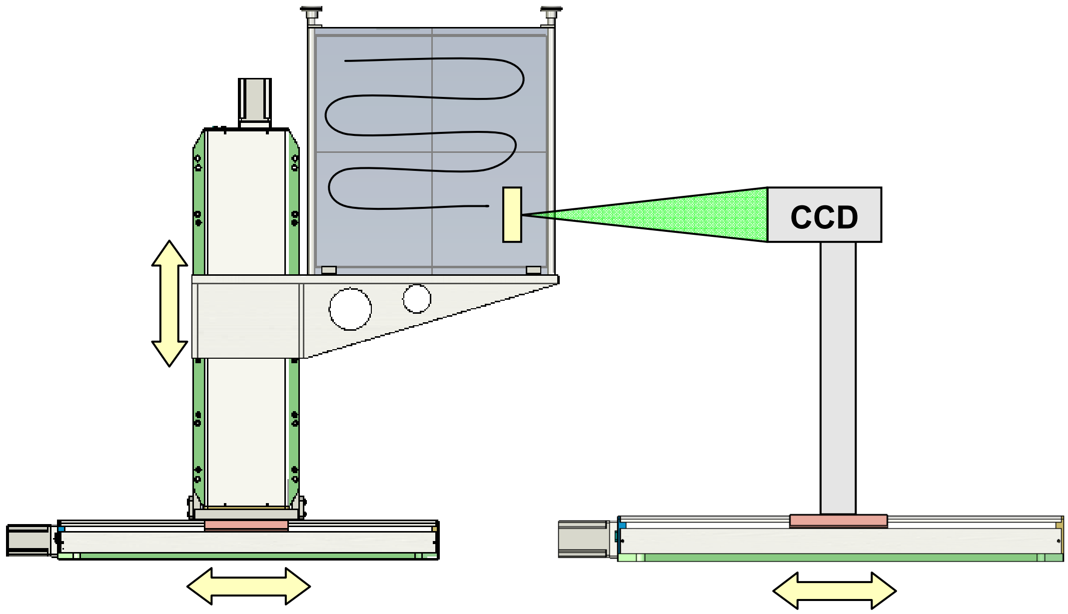


Figure 5: Front view of inclusion detection system. The optic is placed on a XY stages and is raster scanned through a stationary laser beam (coming out of the page). The CCD camera rides on a third stage to maintain focus.

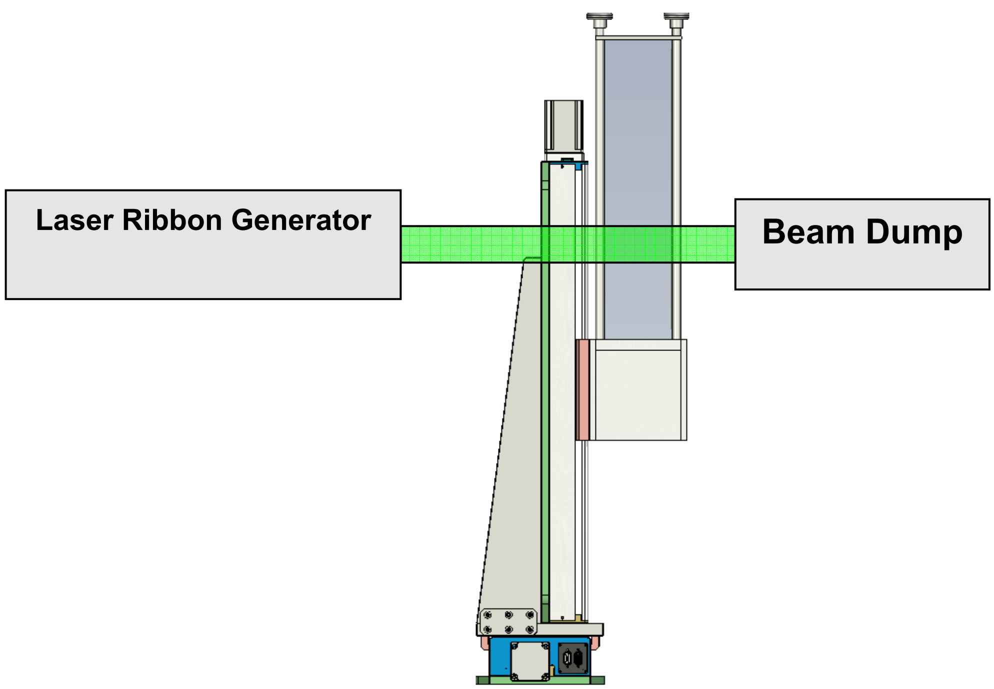


Figure 6: Side view of inclusion detection system. Laser ribbon generator is stationary while stages raster scan optic through laser beam.

The laser is a 532nm 400mW diode pumped solid state device. Its output beam is converted to a near flat top ribbon beam nominally 1mm x 15mm with a hyperbolic lens and a collimating lens. The laser wavelength is a compromise between enhanced defect scatter at shorter wavelengths and reduced bulk scatter at longer wavelengths combined with availability of >100mW of laser power. In addition, the selected monochrome CCD camera has good spectral response at 532nm. The camera is a 480x640 pixel Gig-E camera operating at about 40Hz. The camera frame rate and sensitivity are the limiting factors in the scan speed. If the edges of the optic under test are not polished, a plate is index matched onto the side of the blank to allow imaging into the bulk of the material.

## 5. IMAGE PROCCESSING AND INCLUSION DETECTION

The camera acquires images at a spacing selected so that each defect should be found in two consecutive images. For example, if the beam is 1mm wide x 15mm high, the camera takes an image every 400 microns in the 1mm direction. Each image is then registered to a specific location on the optic. The image is then cropped to remove the scatter from the surfaces. An averaged background is then subtracted (the background is continually updated to account for material changes and laser power drift). The image is then compared to a threshold, if a pixel value exceeds the threshold, the location is noted and the image marked as a containing a possible defect. The images that are selected as having potential defects are then further analyzed to determine if the defects are real. This analysis is a combination of further image processing and review by a user. Figures 7 and 8 demonstrate this process graphically.

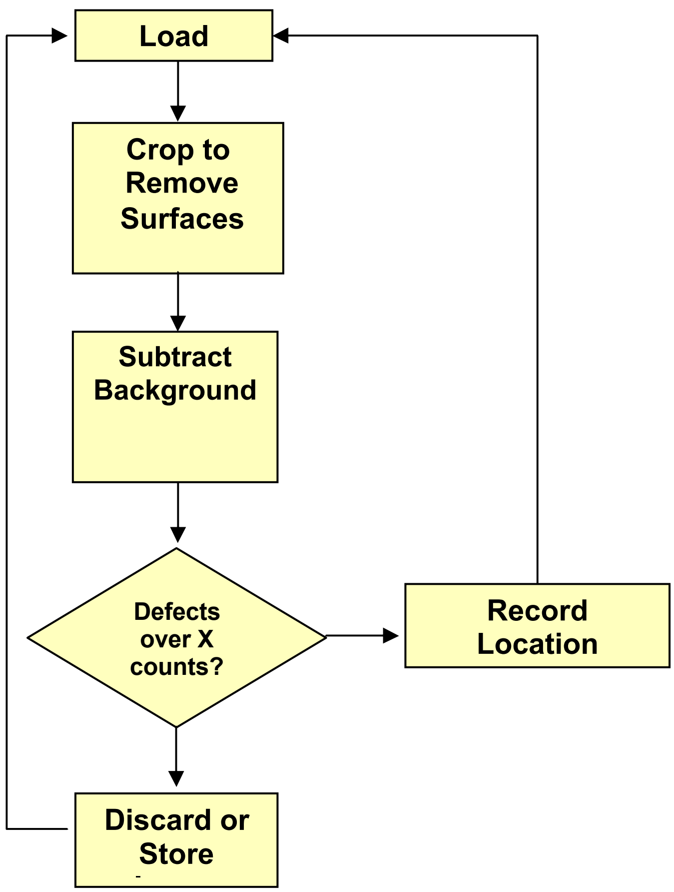


Figure 7: Flow chart for image analysis

(a)

(b)

(c)

(d)

Figure 8: Images from image processing sequence. (a) original image, (b) after edges are cropped, (c) after average is subtracted—note disappearance of band between (b) and (c), (d) binary image showing pixels in white that were over threshold.

# 6. RESULTS

## 6.1 System Performance

The system has detected all known inclusions and a number of previously undetected inclusions while meeting all initial requirements. Actual scan time is 30 minutes well below than the 8- hour requirement. Analysis time is 5-10 minutes. Defects down to 2 microns have been detected and sized, some smaller defects (<2 microns diameter) have been detected, but their size could not be resolved on available instruments.

## 6.2 Examples of detected inclusions

Figure 9 shows an inclusion map of an optic with 18 inclusions. Four of the inclusions where known prior to the scan. AIM found these four inclusions and an additional 14.

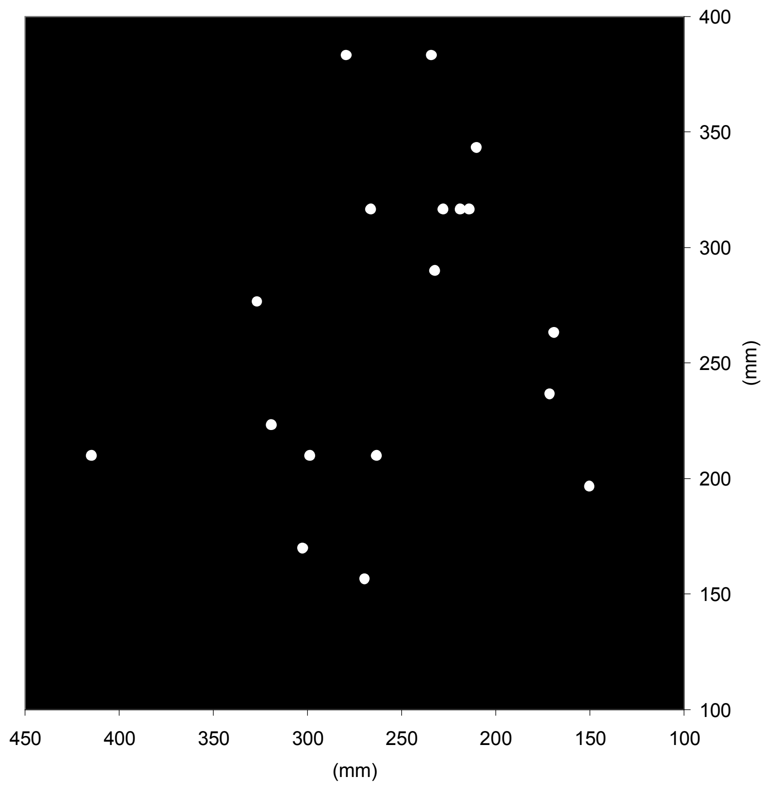


Figure 8: Image showing map of detected inclusions. Each white dot indicates that the AIM detected an inclusion at that location. The horizontal and vertical axis provide a location relative to a known position on the fixture.

Figure 9 shows the image of an bulk defect as detected by the AIM. This defect was previously undetected and is very small. While off line techniques were able to confirm the existence of this defect, none were able to resolve it or provide a reasonable size estimate. Two micron defects have been easily found and resolved; best estimates put this defect at <1 micron.

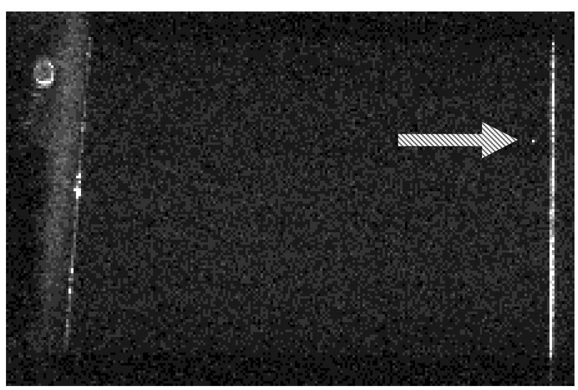

Figure 9: Image of defect as detected by AIM. This defect is too small to resolve with available instrumentation.

## 7. SUMMARY

An inclusion mapping system has been developed for quickly and reliably detecting defects in large volumes of optical material. Defects down to 2 microns and smaller have been detected. All defects previously measured with other instrumentation have been detected.


## 8. ACKNOWLEDGEMENTS

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